Functional Outcomes of Nonunion Scaphoid Fracture Treated by Pronator Quadratus Pedicled Bone Graft

Hassan Hamdy Noaman, MD, Anis Elsayed Shiha, MD,† and Abdel khalek Hafez Ibrahim, MD‡*

Abstract: Between 1998 and 2007, a pronator quadratus pedicled bone graft was performed for 45 patients of ununited scaphoid fracture. One of them had bilateral ununited scaphoid fracture. There were 29 men and 16 women with a median age at operation of 24 (16–32) years. The affected side was the right side (dominant hand) in 32 patients whereas 13 patients had fracture of the nondominant left side. There had been 32 proximal pseudoarthrosis (through or proximal to the junction of the proximal and middle thirds of the bone) and 14 of the middle third of the scaphoid. The original fractures were caused by motor cycle accidents in 23 patients, falling on outstretched hand in 15 patients, and sport injuries in the remaining 7 patients. Surgery was indicated from 5 months to 6 years after injury (average 43 months) because of complaints of pain on heavy work. The fracture has been missed at the initial examination in 23 patients whereas cast immobilization was done for 6 weeks and 3 months in 15 and 7 cases, respectively, that had failed to result in union. There were no preoperative osteoarthritic changes, but in 25 cases, there were avascular necrosis of the proximal fragment of the scaphoid. Forty-three patients showed radiographic union after an average of 14 weeks (12–16 weeks). One patient had dislodgement of the graft and refused to do it again. The average range of movement of wrist improved after operation. Taken as a percentage of the normal range, dorsiflexion increased from 69% to 80%, palmar flexion from 66% to 76%, radial deviation from 45% to 70%, and ulnar deviation from 67% to 84%. Grip strength improved from 82% to 92% of normal. All the patients have been able to return to their former activities with no pain.

Key Words: nonunion scaphoid fracture, vascularized pedicle bone graft, pronator quadratus muscle, avascular bone necrosis

(*Ann Plast Surg* 2011;66: 47–52)

The consensus in the literature is that scaphoid nonunion occurs in ~5% to 10% of scaphoid fractures treated in a plaster cast,[1–4] although Herbert and Fisher[5] reported an incidence in the order of 50%. Nonunion will also occur in an unknown number of unrecognized scaphoid fractures.[6] Several studies have shown that nonunion leads to degenerative arthritis, so prompt diagnosis and treatment is essential.[3,7–9] The ideal treatment of nonunion of the scaphoid remains unsolved and controversial. Displaced fracture fragment and soft tissue interposition can prevent union of acute fractures of the scaphoid carpal bone by interrupting the blood supply.[10] Many authors from all over the world have reported their experience of treatment of scaphoid nonunion with various techniques, but the best surgical treatment is yet to be found.[11] Mc Laughlin[12] is credited with being the first to recommend open reduction and screw fixation of the fracture scaphoid. Herbert and Fisher[5] described the Herbert screw fixation in 1984. Fernandez[13] described a method of fixation using a volar wedge bone graft secured with Kirschner (K) wires in 1984 and in 1990[14] reported the results using the 2.7-mm AO Lag screw injury. Bone graft with or without internal fixation is the standard treatment for symptomatic scaphoid nonunion without osteoarthritis. Cancellous bone grafting first described by Matti and modified by Russe[15] is the most common surgical treatment. Pronator quadratus pedicled bone graft was described by Kawai and Yamamoto[16] in 8 cases. One of these patients had scaphoid fracture in the proximal third. In this article, we present a retrospective study of the functional outcome for treatment of nonunion scaphoid fracture in 45 patients treated by pronator quadratus pedicled bone graft with or without internal fixation. One patient had bilateral nonunion fracture scaphoid. Thirty-two patients had scaphoid fracture in the proximal third. Avascular necrosis of the proximal scaphoid fragment occurred in 25 of them.

SURGICAL TECHNIQUE

A volar curvilinear incision is made over the scaphoid tuberosity and the distal radius. The incision is deepened between the flexor carpi radialis and the radial vessels (Fig. 1). On the distal radius, the pronator quadratus muscles should be identified clearly specially at the radial styloid process. It should be healthy, and a block of bone graft ~15 to 20 mm long is outlined at its distal insertion close to the abductor pollicis longus tendon. Holes are made along the margin of the graft with Kirschner wire to facilitate separation with a fine osteotome. Care is taken that the pronator quadratus is not detached from the harvest bone graft, and the muscle is dissected toward the ulna to secure a pedicle 20-mm thick (Fig. 2). The anterior interosseous vessels need not be identified. If the muscle is too tight to allow easy transfer of the pedicled bone, the ulnar origin of the pronator quadratus is dissected subperiosteally from the ulna through an additional incision over the distal ulna (Fig. 3). The radioscaphocapitate ligament complex is divided, but retained for later repair to the muscle pedicle. The sclerotic bone ends are then excised and freshened with a powered burr to form an oval cavity 10 to 20 mm long and parallel to the axis of the scaphoid. The proximal and distal scaphoid segments are aligned carefully as attraction force is applied to the thumb. This maneuver corrects any intercalated segment instability and allows the grafted bone to be inserted snugly into the cavity in the scaphoid. Two 1.2-mm Kirschner wires are used to fix the proximal and the distal scaphoid segments and the grafted bone if the graft is not well seated inside the cavity. The skin is closed and below elbow cast with a thumb spica is applied. Scaphoid cast was removed 2 weeks postoperative to remove the stitches and to do clean dressing, then a new scaphoid cast for 6 weeks was applied. At 2 months, union was evaluated from radiographs (Figs. 4, 5). The scaphoid cast was applied for another 1 to 2 months. When stable bony union was started, the Kirschner wires and the cast were removed, usually about 3 months after operation.

Received June 10, 2009, and accepted for publication, after revision, January 8, 2010.

From the Departments of *Orthopaedics, Hand and Reconstructive Microsurgical Unit and †Orthopaedics and Traumatology, Sohag Faculty of Medicine, Sohag University, Sohag, Egypt; and ‡Department of Orthopaedics and Traumatology, Assiut Faculty of Medicine, Assiut University, Assiut, Egypt.

Reprints: Hassan Hamdy Noaman, MD, Department of Orthopaedic, Hand and Reconstructive Microsurgical Unit, Sohag Faculty of Medicine, Sohag University, Sohag, Egypt. E-mail: hassan_h@mailcity.com.

ISSN: 0148-7043/11/6601-0047
DOI: 10.1097/SAP.0b013e3181d375f9

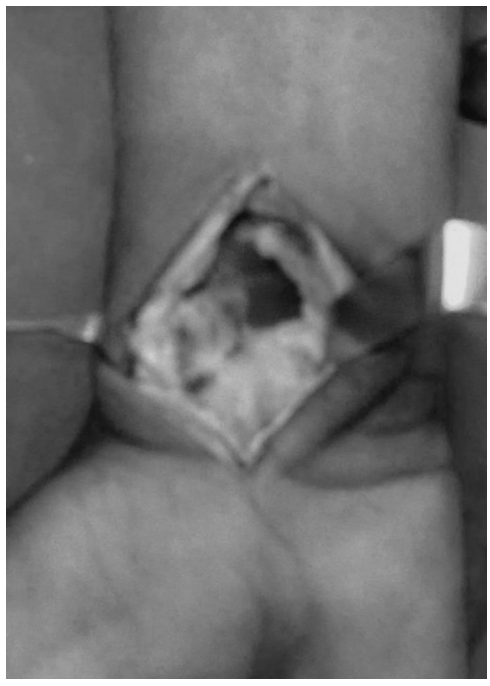

FIGURE 1. Intraoperative photo shows the surgical approach between the flexor carpi radialis and radial blood vessels.

FIGURE 2. Intraoperative photo shows the graft after its detachment from the styloid process of the radius.

Patients

Between 1998 and 2007, a pronator quadratus pedicled bone graft was performed for 45 patients of ununited scaphoid fracture. One of them had bilateral ununited scaphoid fracture. There were 29 men and 16 women with a median age at operation of 24 (16–32) years. The affected side was the right side (dominant hand) in 32 patients whereas 13 patients had fracture of the non dominant left side. There had been 32 proximal pseudoarthrosis (through or proximal to the junction of the proximal and middle thirds of the bone) and 14 of the middle third of the scaphoid. The original fractures were sustained in motor cycle accidents by 23 patients, falling on outstretched hand in 15 patients, and sport injuries in the remaining 7 patients. Surgery was indicated from 5 months to 6 years after injury (average 43 months) because of complaints of pain on heavy work. The fracture has been missed at the initial examination in 23 patients, whereas cast immobilization was done for 6 weeks and 3 months in 15 and 7 cases, respectively, that had failed to result in union. There were no preoperative osteoarthritic changes,

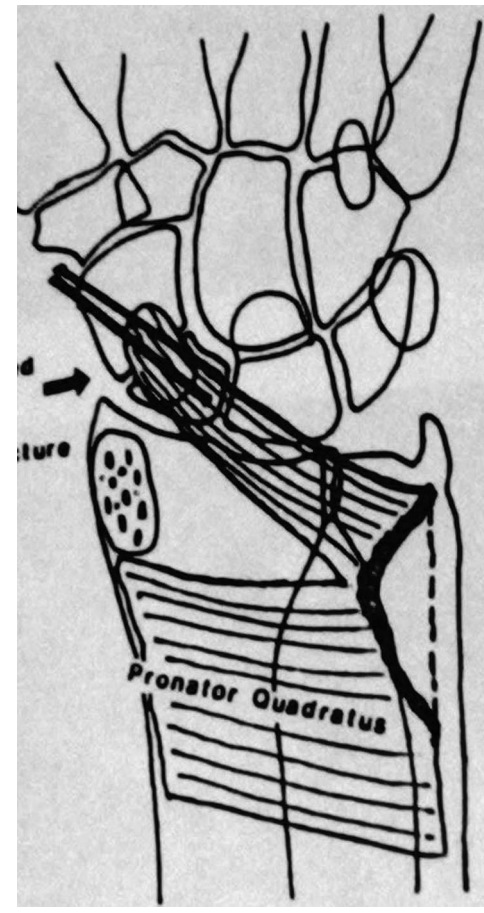

FIGURE 3. Diagram shows the pronator quadratus pedicle bone graft, its insertion into the nonunion scaphoid, and its fixation by 2 K-wires after partial release from the ulnar attachment.

but in 25 cases there were avascular necrosis of the proximal fragment of the scaphoid (Table 1). All patients had vascularized pronator quadratus pedicle bone graft. Bone grafts were secured with K-wires in 12 patients, whereas the remaining bone grafts were press fit into place and was believed to require no fixation for stability.

Results

At operation, 25 cases showed a vascular necrosis of the proximal fragment. The proximal fragment was sclerotic (whitish, no punctuate bleeding during curettage even after tourniquet deflation, stony hard on touch, and giving a sound on clicking). Fibrous nonunion of the scaphoid occurred in the remaining 7 cases of the proximal nonunion. Fourteen of the fracture nonunion of the middle third had cystic changes. At the final follow-up, we assessed the functional outcomes of our procedure by using Herbert and Fisher's score[5] (Table 2). This score includes clinical, radiologic, and patient satisfaction. Clinically, the patients were assessed as regard range of motion of the wrist on all directions and grip strength in the comparison with the other wrist. Radiologic assessment of union required clear evidence of bony trabeculae traversing the graft from the proximal to the distal pole on all 4 scaphoid views, and the fracture line is no longer visible within a minimum follow-up of 6 months. Patient satisfaction was assessed by happy asymptomatic patient, improved with minimal symptoms, unchanged with moder-

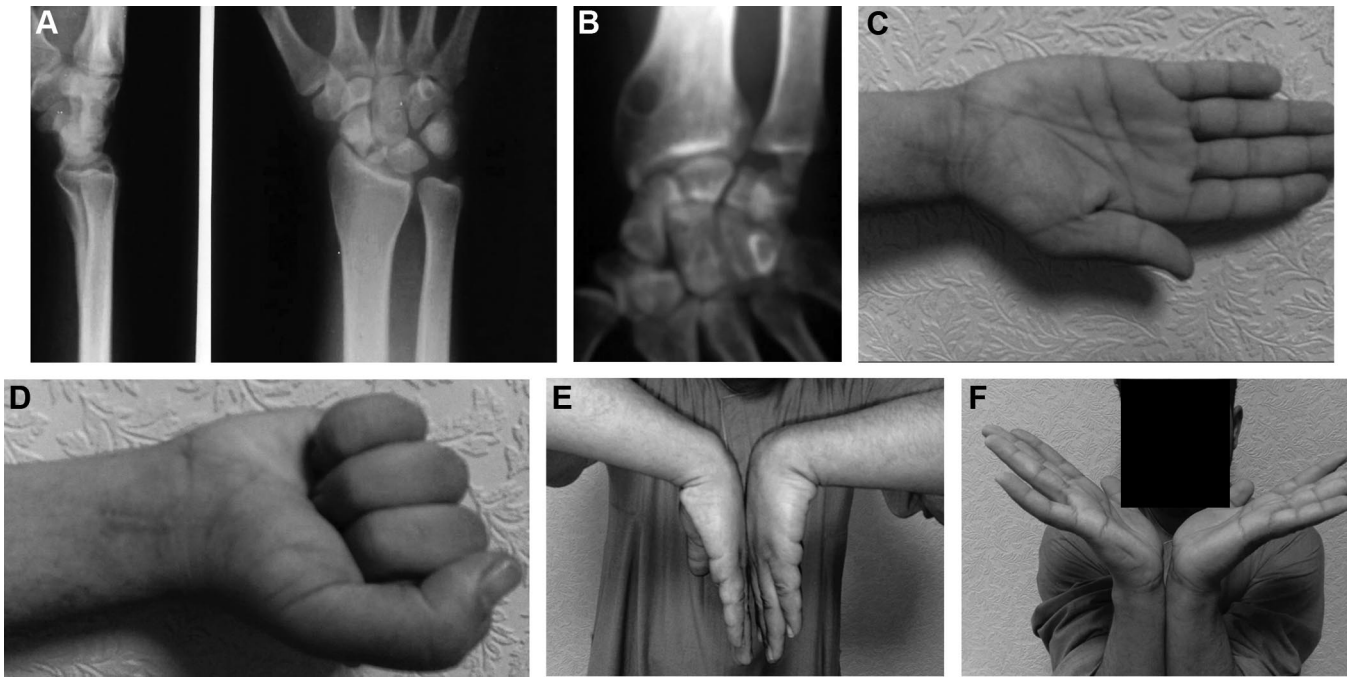

FIGURE 4. Clinical and radiologic follow-up for patient No. 2 in the series. A, Preoperative x-ray shows fracture nonunion of the proximal pole of the scaphoid; B, Postoperative x-ray shows complete union of the scaphoid 8 weeks follow-up, the site of graft is well defined and still empty; C, Complete finger extension with healed scar; D, Complete finger flexion; E, Complete wrist flexion; and F, Complete wrist extension.

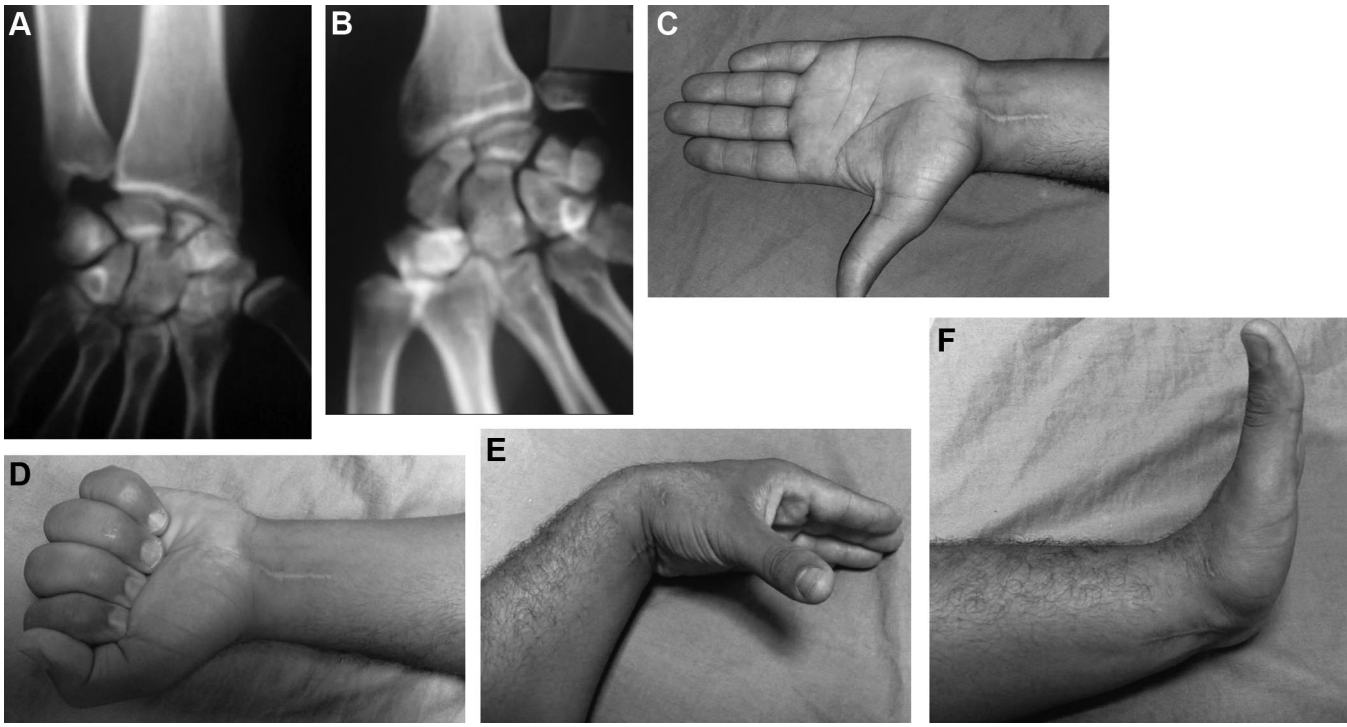

FIGURE 5. Clinical and radiologic follow-up for patient No. 6 in the series. A, Preoperative x-ray shows fracture nonunion with avascula necrosis of the proximal pole of the scaphoid; B, Postoperative x-ray shows complete union of the scaphoid 28 weeks follow-up; C, Complete finger extension with healed scar; D, Complete finger flexion; E, Complete wrist flexion; and F, Complete wrist extension.

TABLE 1. Preoperative Patients' Data

Patient	Age (yr)/ Gender	Side	Mechanism of Injury	Time From Injury (mon)	Initial Treatment	Preop x-ray
1	22/M	R (dom)	MCA	8	SAC 6 wk	Middle third
2	26/M	R (dom)	Falling on outstretched hand	34	None	Proximal third
3	31/M	R (dom)	MCA	46	None	AVN proximal third
4	18/F	L (nondom)	Falling on outstretched hand	7	SAC 6 wk	Middle third
5	30/F	R (dom)	MCA	24	None	AVN proximal third
6	32/M	L(nondom)	MCA	32	None	AVN proximal third
7	16/M	R (dom)	Sport injury	6	SAC 6 wk	Middle third
8	20/F	R (dom)	Sport injury	12	None	AVN proximal third
9	17/F	L(nondom)	Falling on outstretched hand	9	SAC 6 wk	Middle third
10	27/M	L(nondom)	MCA	25	None	AVN proximal third
11	23/F	L(nondom)	MCA	22	None	AVN proximal third
12	19/M	R (dom)	Sport injury	17	SAC	Middle third
13	24/M	R (dom)	MCA	20	None	AVN proximal third
14	19/F	L(nondom)	Falling on outstretched hand	8	SAC 6 wk	Middle third
15	25/M	R (dom)	Sport injury	30	None	AVN proximal third
16	27/F	R (dom)	Falling on outstretched hand	10	SAC 6 wk	Middle third
17	20/M	R (dom)	MCA	7	SAC 6 wk	Middle third
18	21/M	R & L	Sport injury	12	SAC 6 wk	AVN proximal third
19	30/M	L(nondom)	MCA	18	None	Middle third
20	29/M	R (dom)	MCA	19	None	AVN proximal third
21	28/F	L(nondom)	MCA	8	SAC 6 wk	Middle third
22	21/M	R (dom)	Falling on outstretched hand	16	SAC 3 mo	Proximal third
23	20/F	R (dom)	MCA	9	SAC 6 wk	Middle third
24	24/M	R (dom)	Sport injury	23	None	AVN proximal third
25	25/F	L(nondom)	MCA	34	None	AVN proximal third
26	22/M	R (dom)	Falling on outstretched hand	45	None	AVN proximal third
27	18/M	R (dom)	MCA	8	SAC 6 wk	Proximal third
28	!7/F	R (dom)	Falling on outstretched hand	6	SAC 6 wk	Middle third
29	!9/M	R (dom)	MCA	17	SAC 3 mo	Middle third
30	22/M	L(nondom)	Falling on outstretched hand	15	SAC 3 mo	Proximal third
31	25/M	R (dom)	Falling on outstretched hand	22	None	AVN proximal third
32	21/M	R (dom)	MCA	19	None	Middle third
33	18/F	R (dom)	MCA	7	SAC 6 wk	Proximal third
34	30/M	R (dom)	Falling on outstretched hand	25	None	AVN proximal third
35	28/M	L(nondom)	MCA	22	None	AVN proximal third
36	24/M	R (dom)	MCA	32	None	Proximal third
37	20/M	R (dom)	Falling on outstretched hand	8	SAC 6 wk	AVN proximal third
38	18/M	R (dom)	sport injury	48	None	AVN proximal third
39	21/F	L(nondom)	MCA	26	SAC 3 mon	AVN proximal third
40	30/F	L(nondom)	MCA	44	None	AVN proximal third
41	27/M	R (dom)	Falling on outstretched hand	52	None	Proximal third
42	23/M	R (dom)	Falling on outstretched hand	12	SAC 6 wk	AVN proximal third
43	26/F	R (dom)	MCA	16	SAC 3 mon	AVN proximal third
44	20/F	R (dom)	Falling on outstretched hand	22	None	AVN proximal third
45	18/M	R (dom)	MCA	6	SAC 3 mon	AVN proximal third

AVN indicates avascular necrosis; dom, dominant; MCA, motor car accident; nondom, nondominant; SAC, short arm cast.

ate symptoms, or worse with severe symptoms. Forty-three patients showed radiographic union after an average of 14 weeks (12–16 weeks, Table 3). One patient had dislodgement of the graft and refused to do it again. The failure of graft occurred in one patient. The avascular proximal pole fragment was excised. The patient did not experience any further pain. The average range of movement of wrist improved after operation. Taken as a percentage of the normal range, dorsiflexion increased from 69% to 80%, palmar flexion from 66% to 76%, radial deviation from 45% to 70%, and ulnar deviation from 67% to 84%. Grip strength improved from 82% to 92% of normal. All the patients have been able to return to their former activities with no pain (Figs. 5, 6). The overall results used Herbert and Fisher's score was excellent in 92%, good in 4%, fair in 2%, and poor in 2% (Table 4).

TABLE 2. Herbert and Fisher's Score

Result	Grade	Patient Satisfaction	Clinical Result	Radiographic Result
Excellent	0	Very happy asymptomatic	Normal function unrestricted use	Sound union no deformity
Good	1	Improved minimal symptoms	Minimal loss of function unrestricted use	Apparent union minimal deformity
Fair	2	Unchanged moderate symptoms	Some restriction marked loss of function	Doubtful union marked deformity
Poor	3	Worse severe symptoms	Marked loss of function restricted use	Non union loosening of the fixation

TABLE 3. Postoperative Follow-up and Results of Pronator Quadratus Pedicle Bone Graft for Nonunion Fracture Scaphoid

	Follow-up (mon)	Time to Union (wk)	Herbert and Fisher's Score
1	32	12	Excellent
2	20	12	Excellent
3	28	12	Excellent
4	10	12	Excellent
5	36	12	Excellent
6	28	12	Excellent
7	12	12	Excellent
8	42	12	Excellent
9	27	12	Excellent
10	15	15	Excellent
11	20	13	Excellent
12	17	14	Excellent
13	24	12	Excellent
14	42	15	Excellent
15	33	14	Excellent
16	41	16	Excellent
17	18	16	Excellent
18	42	16	Excellent
19	11	12	Excellent
20	24	14	Excellent
21	19	15	Excellent
22	22	12	Excellent
23	26	14	Excellent
24	21	14	Excellent
25	29	13	Excellent
26	22	16	Excellent
27	12	16	Excellent
28	35	12	Excellent
29	52	16	Excellent
30	28	15	Excellent
31	25	13	Excellent
32	19	12	Excellent
33	39	15	Excellent
34	27	14	Excellent
35	35	16	Excellent
36	19	13	Excellent
37	12	13	Excellent
38	32	12	Excellent
39	20	14	Excellent
40	45	15	Excellent
41	16	12	Excellent
42	22	18	Good
43	10	18	Good
44	27	Non union	Fair
45	6	Graft dislodgement	Poor

TABLE 4. The Overall Results of Pronator Quadratus Pedicle Bone Graft for Nonunion Fracture Scaphoid

Result	No. Scaphoid Grafts	Percentage (%)
Excellent	42	91.5
Good	2	4.5
Fair	1	2
Poor	1	2
Total	46	100

DISCUSSION

Nonunion of the scaphoid is defined as a failure of bone trabeculae to cross the fracture site. Usually, the diagnosis is made if there is no radiographic evidence of union at 6 months after the injury. Various treatments for scaphoid nonunion have been advocated. The Russe inlay bone graft technique is still a standard operation. Although a union rate of 92% has been reported when the proximal pole was well vascularized, it has failed to achieve union when proximal pole vascularity was fair or absent. Furthermore, at least 5 months of immobilization were needed, and this might have caused the limitation of motion in 35 of the 45 patients in the series of Green.[17]

VBGs are currently accepted in the treatment of scaphoid nonunions. Many advantages have been described. Bone viability and strength are preserved and union seems to be faster.[18,19] It is also believed to provide osteogenic potential even in a poorly vascularized bed.[20]

Various VBGs have shown excellent results in the treatment of scaphoid nonunions.[21–23] Buechler and Nagy[24] suggested that a VBG from the dorsoradial aspect of the distal radius was the most logical treatment of scaphoid nonunion. A VBG is indicated for scaphoid nonunions with a small proximal pole fragment, scant or absent bleeding points on the fragments, and perhaps in longstanding nonunions.[23,24] Previous reports have also advocated VBGs as a secondary procedure after failed conventional NVBGs.[24–26]

Several VBGs have been described in the literature. These include the use of the 1, 2 intercompartmental supraretinacular artery, pedicled grafts based on the ulnar artery or the palmar carpal artery, the radial styloid fasciosteal graft, and pedicled grafts from the index finger metacarpal and the thumb metacarpal, implantation of a vascular leash alone from the second dorsal intermetacarpal artery in combination with bone grafting also has been reported, free VBG from the iliac crest and the medial femoral supracondylar region, and the pronator quadratus pedicle bone graft.[16,24–30]

Pronator quadratus pedicle bone graft has many advantages. The anterior approach not only preserves the blood supply of the scaphoid but also leads to minimum loss of wrist flexion-extension.[28] This was evident in our series, which had overall postoperative improvement of the flexion-extension arc of 10% and of the radial-ulnar deviation are of 15%. Grip strength was improved from 82% to 92% of normal that was of a great benefit for manual workers. Correction of the dorsal intercalated segment instability malalignment was considered as another factor that helped to increase the postoperative range of motion, especially extension. The short healing time of the VBG allowed the patients to

start range of motion exercises as early as 6 weeks after operation. In our series, the average time of union was longer (14 weeks) because of the presence of avascular bone necrosis in 25 scaphoid nonunion and fracture nonunion of the proximal third in 7 scaphoid. Pain, which was the main problem for the patients, was completely relieved in all cases. This is the second series described the use of pronator quadratus pedicle bone graft for nonunion fracture scaphoid. The first series was described by Kawai and Yamamoto.[16] They presented 8 cases of old ununited scaphoid fracture. The fracture was in the distal third in 1 case, the middle third in 6, and the proximal third in 1. It was transverse in 6 cases and oblique in 2. There were no preoperative osteoarthritic changes, but in 1 case there were sclerotic changes in the proximal part of the scaphoid. All 8 cases showed radiographic union after an average of 8.5 weeks. The average range of movement of the wrist improved after operation. All the patients have been able to return to their former activities with no pain. In our series, there had been 32 proximal pseudoarthrosis (through or proximal to the junction of the proximal and middle thirds of the bone) and 14 of the middle third of the scaphoid. There were no preoperative osteoarthritic changes, but in 25 cases there were sclerotic changes in the proximal part of the scaphoid. At operation, 25 cases showed a vascular necrosis of the proximal fragment. Fibrous nonunion of the scaphoid occurred in the remaining 7 cases of the proximal nonunion. Fourteen of the fracture nonunion of the middle third had cystic changes. Forty-three patients showed radiographic union after an average of 14 weeks (12–16 weeks). One patient had dislodgement of the graft and refused to do it again. Failure of graft occurred in 1 patient. The avascular proximal pole fragment was excised. The patient did not experience any further pain. The average range of movement of wrist improved after operation. Taken as a percentage of the normal range, dorsiflexion increased from 69% to 80%, palmar flexion changed from 66% to 76%, radial deviation from 45% to 70%, and ulnar deviation from 67% to 84%. Grip strength improved from 82% to 92% of normal. All the patients except one have been able to return to their former activities with no pain.

There are other 3 series described vascularized bone graft from the palmar aspect of the distal radius for treatment of nonunion fracture scaphoid. The first series was published by Kuhlmann et al.[31] They presented 3 cases of nonunion scaphoid treated by vascularized bone graft from the volar and ulnar aspect of the distal radius supplied by the palmar carpal artery. They reported that favorable results have been obtained. The second series was published by Mathoulin and Haerle.[22] They presented 17 cases of nonunion scaphoid treated by vascularized bone graft from the volar and ulnar aspect of the distal radius supplied by the palmar carpal artery. Union was obtained in all cases at an average of 8 weeks. The third series was published by Dailiana et al.[28] Their series included 9 patients who had nonunion waist of the scaphoid treated by vascularized bone grafts from the radius. Union obtained in all cases between 6 and 12 weeks.

CONCLUSIONS

Pronator quadratus pedicle bone graft is a solution for nonunion fracture scaphoid especially proximal pole fragment with or without avascular necrosis and failed previous treatment. The anterior approach not only provides a good solution for nonunion but also corrects the dorsal intercalated segment instability. It is not indicated for previously injured pronator quadratus muscle.

REFERENCES

1. Gelberman RH, Wolock BS, Siegel DB. Fractures and non-unions of the carpal scaphoid. *J Bone Joint Surg Am*. 1989;71:1560–1564.
2. Leslie IJ, Dickson RA. The fractured carpal scaphoid. Natural history and factors affecting outcome. *J Bone Joint Surg Br*. 1981;63B:225–230.
3. Mack GR, Bosse MJ, Gelberman RH. The natural history of scaphoid non-union. *J Bone Joint Surg Am*. 1984;66:504–509.
4. Procter MT. Non-union of the scaphoid: early and late management. *Injury*. 1994;25:15–20.
5. Herbert TJ, Fisher WE. Management of the fractured scaphoid using a new bone screw. *J Bone Joint Surg Br*. 1984;66:114–123.
6. Prosser GH, Isbister ES. The presentation of scaphoid non-union. *Injury*. 2003;34:65–67.
7. Lindstrom G, Nystrom A. Natural history of scaphoid non-union, with special reference to "asymptomatic" cases. *J Hand Surg Br*. 1992;17:697–700.
8. Ruby LK, Stinson J, Belsky MR. The natural history of scaphoid non-union. A review of fifty-five cases. *J Bone Joint Surg Am*. 1985;67:428–432.
9. Vender MI, Watson HK, Wiener BD, et al. Degenerative change in symptomatic scaphoid nonunion. *J Hand Surg Am*. 1987;12:514–519.
10. Ricardo M. The effect of ultrasound on the healing of muscle-pediculated bone graft in scaphoid non-union. *Int Orthop*. 2006;30:123–127.
11. Christodoulou LS, Kitsis CK, Chamberlain ST. Internal fixation of scaphoid non-union: a comparative study of three methods. *Injury*. 2001;32:625–630.
12. McLaughlin HL. Fracture of the carpal navicular (scaphoid) bone; some observations based on treatment by open reduction and internal fixation. *J Bone Joint Surg Am*. 1954;36A:765–774.
13. Fernandez DL. A technique for anterior wedge-shaped grafts for scaphoid nonunions with carpal instability. *J Hand Surg Am*. 1984;9:733–737.
14. Fernandez DL. Anterior bone grafting and conventional lag screw fixation to treat scaphoid nonunions. *J Hand Surg Am*. 1990;15:140–147.
15. Russe O. Fracture of the carpal navicular. Diagnosis, non-operative treatment, and operative treatment. *J Bone Joint Surg Am*. 1960;42A:759–768.
16. Kawai H, Yamamoto K. Pronator quadratus pedicled bone graft for old scaphoid fractures. *J Bone Joint Surg Br*. 1988;70:829–831.
17. Green DP. The effect of avascular necrosis on Russe bone grafting for scaphoid nonunion. *J Hand Surg Am*. 1985;10:597–605.
18. Dell PC, Burchardt H, Glowczewskie FP Jr. A roentgenographic, biomechanical, and histological evaluation of vascularized and non-vascularized segmental fibular canine autografts. *J Bone Joint Surg Am*. 1985;67:105–112.
19. Shaffer JW, Field GA, Wilber RG, et al. Experimental vascularized bone grafts: histopathologic correlations with postoperative bone scan: the risk of false-positive results. *J Orthop Res*. 1987;5:311–319.
20. Doi K, Oda T, Soo-Heong T, et al. Free vascularized bone graft for nonunion of the scaphoid. *J Hand Surg Am*. 2000;25:507–519.
21. Guimberteau JC, Panconi B. Recalcitrant non-union of the scaphoid treated with a vascularized bone graft based on the ulnar artery. *J Bone Joint Surg Am*. 1990;72:88–97.
22. Mathoulin C, Haerle M. Vascularized bone graft from the palmar carpal artery for treatment scaphoid nonunion. *J Hand Surg Br*. 1998;23:318–323.
23. Zaidemberg C, Siebert JW, Angrigiani C. A new vascularized bone graft for scaphoid nonunion. *J Hand Surg Am*. 1991;16:474–478.
24. Buechler U, Nagy L. The issue of vascularity in fractures and non-union of the scaphoid. *J Hand Surg Br*. 1995;20:726–735.
25. Boyer MI, von Schroeder HP, Axelrod TS. Scaphoid nonunion with avascular necrosis of the proximal pole. Treatment with a vascularized bone graft from the dorsum of the distal radius. *J Hand Surg Br*. 1998;23:686–690.
26. Uerpairojkit C, Leechavengvongs S, Witoonchart K. Primary vascularized distal radius bone graft for nonunion of the scaphoid. *J Hand Surg Br*. 2000;25:266–270.
27. Steinman SP, Bishop AT, Berger RA. Use of the 1,2 intercompartmental supraretinacular artery as a vascularized pedicle bone graft for difficult scaphoid nonunion. *J Hand Surg Am*. 2002;27:391–401.
28. Dailiana ZH, Malizos KN, Zachos V, et al. Vascularized bone grafts from the palmar radius for the treatment of waist nonunions of the scaphoid. *J Hand Surg Am*. 2006;31:397–404.
29. Sotereanos DG, Darlis NA, Dailiana ZH, et al. A capsular-based vascularized distal radius graft for proximal pole scaphoid pseudoarthrosis. *J Hand Surg Am*. 2006;31:580–587.
30. Moran SL, Cooney WP, Shin AY. The use of vascularized grafts from the distal radius for the treatment of Preiser's disease. *J Hand Surg Am*. 2006; 31:705–710.
31. Kuhlmann JN, Minoun M, Boabighi A, et al. Vascularized bone graft pedicled on the volar carpal artery for non-union of the scaphoid. *J Hand Surg Br*. 1987;12:203–210.